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Analysis Procedure for Spreader Bar Lift Stability

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Table of Contents

Background

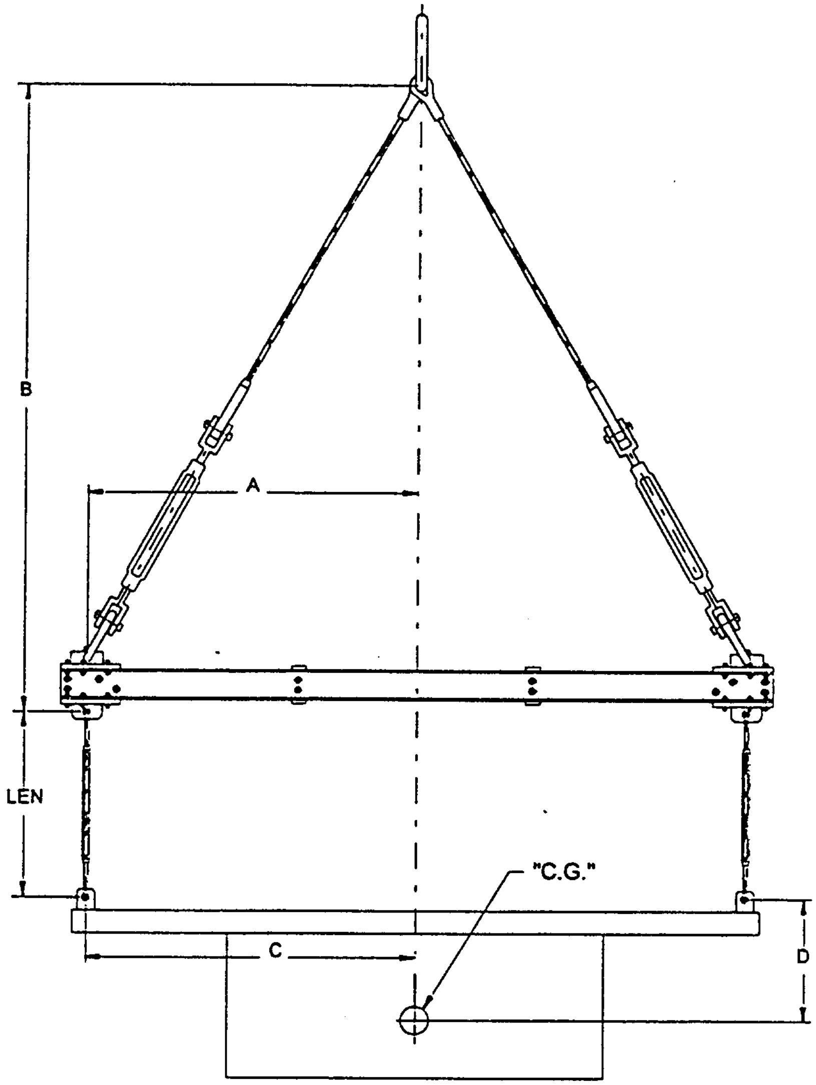
This specification is intended to aid the analyst in determining whether a spreader bar lift is stable. In general if the lowest lift attach point is above the payload's center of gravity then the lift is deemed stable. If the lowest lift attach point is below the center of gravity, then further analysis is required. This procedure is intended to expand on the JPL spreader bar lift stability specification found in appendix G of JPL Document #D6904 Dated February 1990. Additional analysis methods are offered. A further analysis shows that we must limit the lifts from being very tall and thin, even though they meet the JPL specification. Alternative methods to obtaining stability for these types of lifts are discussed. Tag Line usage, placement, and operational considerations with respect to lift height are also covered.

Classification of Spreader Bar Lifts

Spreader bar lifts fall into two major categories. The first is those in which the load center of gravity is below the lowest lift attach point of the lift arrangement. These lifts are inherently stable. For any angle of the spreader bar, the load raises. The other category, which is the subject of this procedure, are lifts in which the load center of gravity is above the lowest attach points of the lift arrangement. These lifts must be analyzed to determine if they will be stable under all conditions. In some configurations of these lifts, they may be marginally stable, however, experience shows that one must ensure stability under all lift conditions to prevent injury or damage. It is the intention of this specification to aid in the development of the analysis for these latter type lifts.

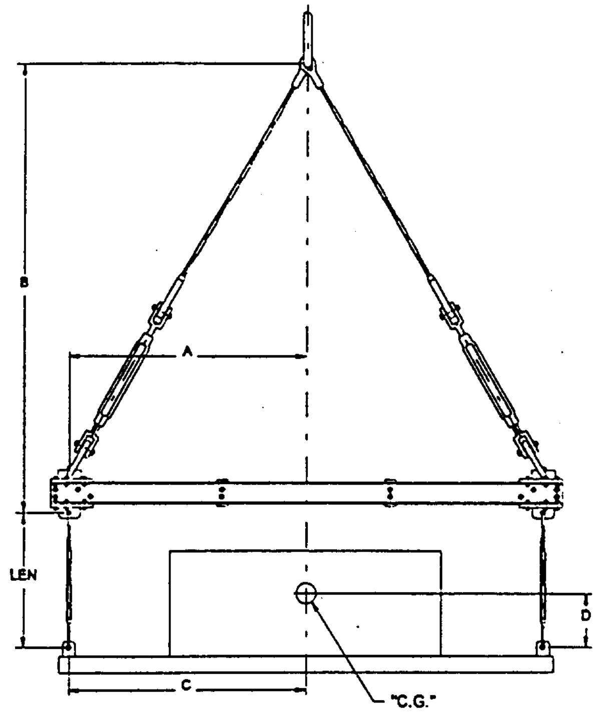
Once a lift is determined to be of the type that the load center of gravity is above the lowest lift point of the lift arrangement, we must further determine if it is a parallel lift. Each of the main two sub-categories of lifts, symmetric and asymmetric, can have parallel lifts. Both symmetric and asymmetric lifts further have three sub-categories, parallel, bird-cage, and, umbrella lifts. Asymmetric lifts are those in which the center of gravity of the load does not fall along a perpendicular bisector of the upper spreader bar. The lifts typically have different length slings or wires from the spreader bar up to the hook lift point

Load Center of Gravity Below Attach Points



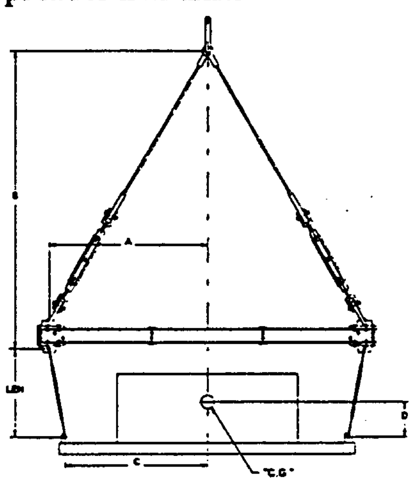
Load Center of Gravity Above Attach Points

Symmetric Parallel Spreader Bar Lifts



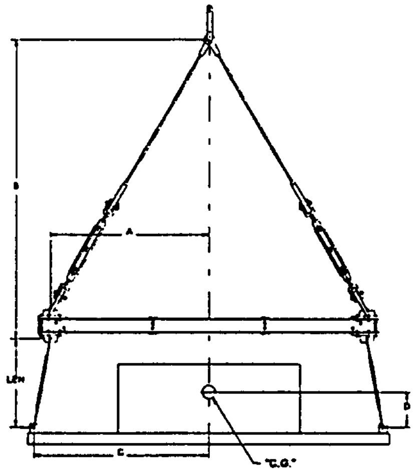
These lifts are defined as lifts using a spreader bar where the load center of gravity falls on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the slings between the spreader bar and the lower platform fall vertically and thus are parallel.

Symmetric Bird-Cage Spreader Bar Lifts



These lifts are defined as lifts using a spreader bar where the load center of gravity falls on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the spreader bar is longer than the lower platform so that the lower ends of the slings are closer together than their top ends.

Symmetric Umbrella Spreader Bar Lifts



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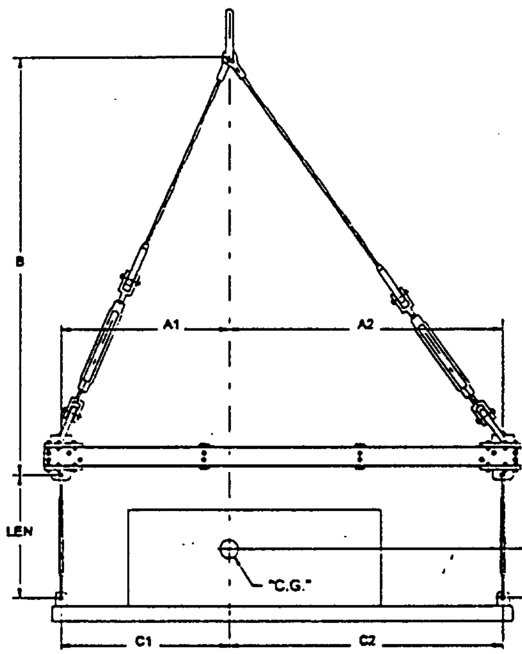
Asymmetric Parallel Spreader Bar Lifts



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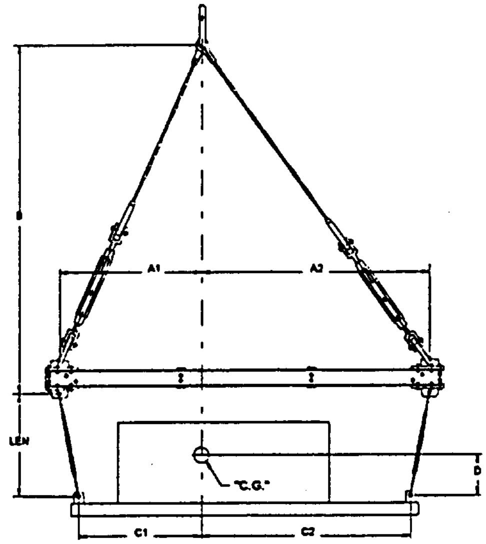
Asymmetric Bird-Cage Spreader Bar Lifts



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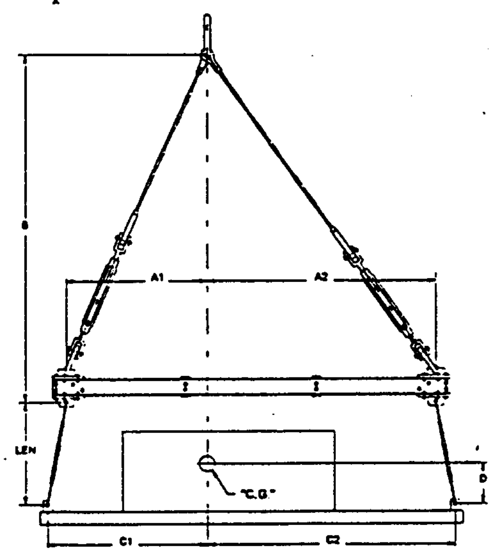
Asymmetric Umbrella Spreader Bar Lifts



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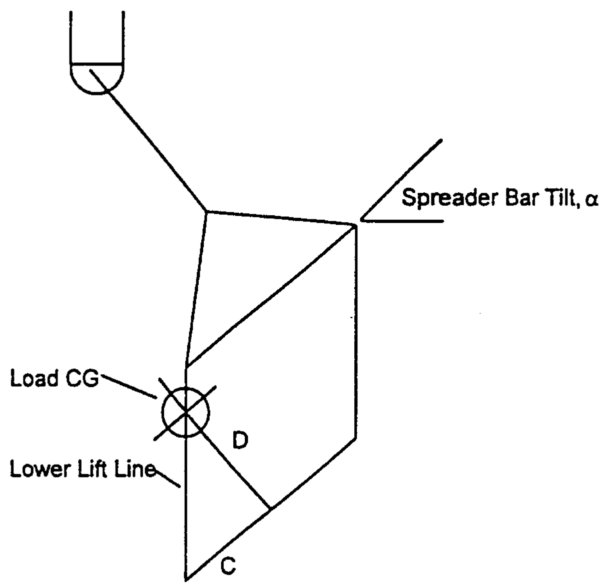
Discussion

Stability

A spreader bar lift is stable, when the Load Center of Gravity (LCG) raises with spreader bar tilt. However, a lift can meet the stability criterion but will flip over with only a small angular excursion of the spreader bar. This occurs when D is large compared to C. Whenever the LCG passes outside the lower lift lines, a tipping moment



Impending Flip-over

is created that will allow the load to flip over. This will occur especially if the load is tall, thin and is lifted using the spreader bar arrangement. Therefore, a flipping criterion must also be met.

The bird cage lifts are the least stable due to their kinematics. Efforts should be made to change the lift points to obtain a parallel type.

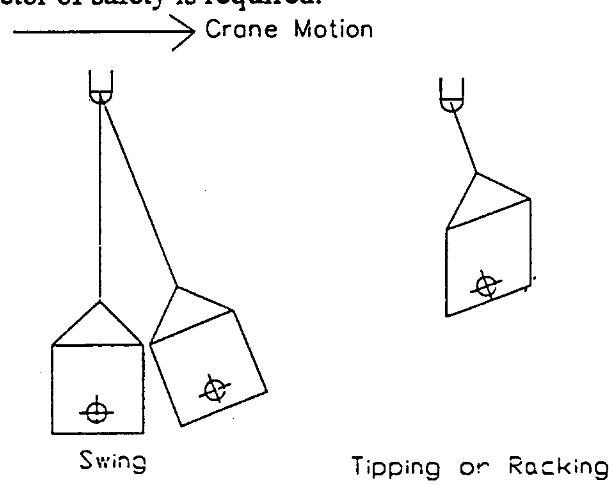
The umbrella lifts are the most stable due to their kinematics. The extreme of an umbrella lift is one in which the slings from the hook form a straight line to the lower platform attach points. In these cases and especially those in which the spreader bar is smaller than a straight line between the hook and the lower platform, the spreader should be removed and slings attached from the lower platform directly to the hook. This lift without the spreader bar will then be stable as long as the center of gravity falls within the lifting lines.

Energy Considerations

Various procedures can cause energy to 'move' the center of gravity to an area that would cause instability. Handling can input enough energy into the system to cause it to flip. Tag lines used during handling impart force into the lift system. A 300 lb tag line operator hanging on an inappropriate placed tag line would significantely change the load center of gravity and the corresponding spreader bar tilt determined using standard static analysis. Irresponsible tag line operator can get a load oscillating enough to topple almost any load. One solution to this is to place the tag lines below the load center of gravity and minimize vertical loading on the payload. Fortunately, trained tag line operators are responsible, not negligent, and will not use the tag line to impart excessive energy into the lift system.

Another method of imparting energy into the load is through the crane itself. A worst-case scenario is when the crane abruptly stops after traversing at full speed. The kinetic energy of the load can then be enough to impart enough energy into the load to cause it to flip. An abrupt crane stoppage could occur when the power is lost and the brakes lock on, or if the crane hits an obstruction or an end-stop. Thus, we calculate the energy of the load traveling at full speed, and compare that kinetic energy with the energy it will take to tip the spreader bar enough to cause the center of gravity to pass outside the lower sling lines and topple the load.

This calculation is conservative since it neglects the energy which would be imparted to cause payload lift sling swinging motion, and assumes all energy to be taken by spreader bar tipping or racking. Because of the very conservative estimate of the tipping energy, no factor of safety is required.



It is further noted that tipping or racking is more likely for crane motion with the payload at maximum height. It is therefore strongly recommended that, if at all possible, crane motion should be minimized with the payload in the full height position.

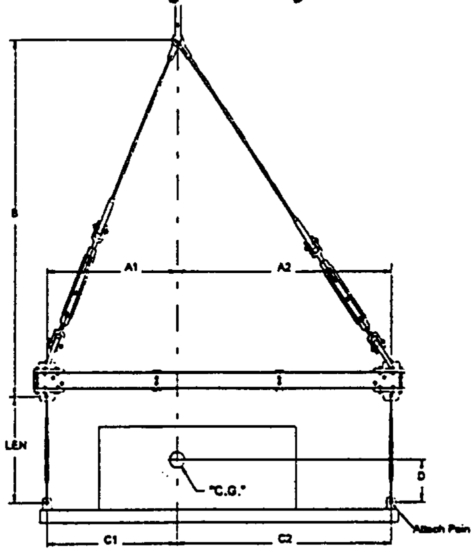
Looking at the equations for the kinetic and potential energies, the mass of the load can be divided into both sides, and thus is eliminated. Now, we have the massless kinetic energy of the load, $\frac{1}{2} \bullet V^2$, and the massless potential energy, $g \bullet \Delta cg$, wrt change in height of the Load Center of Gravity(LCG) caused by tilting the spreader bar from horizontal. The maximum crane velocity is directly calculated.

The analysis starts with the categorization of the lift arrangement, continues with checking the stability and flipping criteria, and concludes with a look at the energy or force to cause tipover. It is important that the lift arrangement be carefully documented with each part labeled to insure the actual lift arrangement matches the stability analysis.

Analysis Procedure

Summary

Lift Stability Analysis Summary



For All Lift Configurations

$$B > 1.5\left(\frac{A_i^2}{C_i^2}\right) \bullet D$$

If cg Below Attach Point Stable

Parallel Symmetric Lifts

$$\alpha_{flip-over} = \tan^{-1}\frac{C}{D}$$

$$\Delta cg = B(1-\cos\alpha) - D(1-\cos\alpha)$$

All non-parallel and Asymmetric Lifts

Graphical Solution to determine Δcg and α

Maximum Crane Velocity $V_{flip} = \sqrt{2 \bullet \Delta cg \bullet gravity}$

Procedure

Stability Criterion

For all Lift Configurations determine of the values of A1, A2, B, C1, C2, D, and Length as shown on Figure 1.

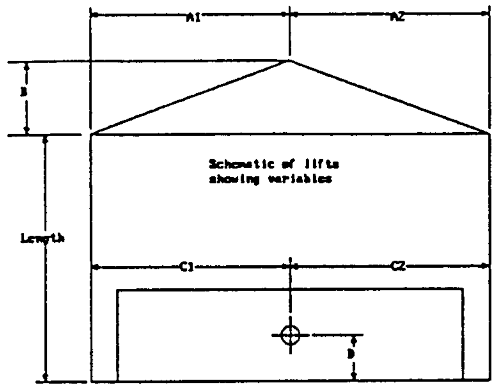


Figure 1 - Diagram of Variables (from program)

Both of the pairs, A_1 & C_1 and A_2 & C_2, should be checked for asymmetric lifts. The following criterion shall be met for a lift configuration to be considered stable.

$$B \geq 1.5 \bullet \left(\frac{A_i^2}{C_i^2} \right) \bullet D$$

Flipping Criterion

The angular excursion which causes the load to flip-over should also be checked. The following formula describes the Flipping Angle in terms of the lift geometry for parallel lifts only.

$$\alpha_{Flip-over} = TAN^{-1} \frac{C_i}{D}$$

The Flipping Angle should be some reasonable large number so the lift has a large tolerance for handling. A good rule of thumb to ensure that the crane will not impart enough energy to reach the flip-over angle is $C > 2 \bullet D$.

Maximum Crane Velocity

Using the set of C1 & D or C2 & D which gives the smallest ratio C/D.

1. For parallel lifts, the flip-over angle can be calculated directly.

$$\alpha_{Flip-over} = TAN^{-1} \frac{C_i}{D}$$

In the case of non-parallel lifts, the angular excursion of the spreader bar when the LCG passes outside of the lift lines must be determined graphically or by numeric interation.

2. At the Flip-over angle, determine the vertical movement of the LCG and calculate the crane velocity which imparts enough energy to flip the load using the following.

$$V_{flip} = \sqrt{2 \bullet \Delta cg \bullet gravity}$$

3. The bridge or trolley velocity shall not be operated faster than V_{flip}. Note that the available speeds are limited to the discrete steps corresponding to the crane speeds, and the reduced speed must be one obtainable by the crane being used.

Solutions to an Unstable Lift Situation

The easiest way to increase lift stability is to increase the vertical distance of the hook from the upper spreader bar, dimension B. In some cases due to limited ceiling heights or tall obstacles, this is not possible. The next solution is to lower the vertical distance between the load center of gravity and the lowest lift points. This can be done by building a rigid structure onto the lower platform and re-installing the lower lift point attachments. A re-analysis is necessary to ensure that stability is achieved. A third way to ensure stability is to essentially make the lower platform rigid to the spreader bar by use of cross bracing or cross members.

The stability requirements described herein shall be followed regardless of the Lift Classification or the analysis method chosen. Cross bracing will change the classification of the lift. The problem becomes one for structural analysis, rather than strictly a stability analysis. The structural analysis must ensure that each member can take the load in all possible load tilt conditions.

Other Considerations

Tag Lines

Tag lines should be documented as part of the Lift Configuration. The tag lines should be attached to the spreader bar or the lower platform such that vertical loads on either of these members are minimized. The tag lines should be used only for the dampening of load swinging or gentle rotation about the lift axis. The tag lines should never be used for vertical adjustment of the load's tilt. Tag line operators must notify the lift engineer if they notice that vertical loads are needed for any reason, since a shift in center of gravity may have occurred, or the lift has become unstable from another cause.

Lift Height

During the process of a lift, the risks to equipment and personnel increase as the lift is raised or as the speed increases. For this reason, should large traversals of the bridge crane or trolley be required, the load should be kept as close to the floor as is practical, taking into account the possible swinging of the load due to crane jogs. Safety is <u>not</u> increased if the load is lifted so that the hoist is close to its upper limit, in fact, all this does is increase the amount of energy that the crane imparts into tipping as the bridge or trolley is jogged, started or stopped. In addition, it increases the potential energy of the load thus increasing the damage should the load fall in a worst case scenario. At all times, personnel must be kept clear of the load and as the lift is increased. The space of clearance from the load should be increased to approximately 1.5 times the height of the load.